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A SEQUENTIAL K-GROUP RANDOM ALLOCATION METHOD WITH APPLICATIONS--ETC(U)

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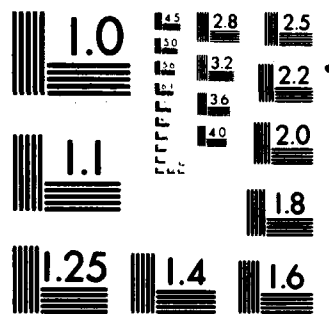
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November, 1980

A SEQUENTIAL k-GROUP RANDOM ALLOCATION
METHOD WITH APPLICATIONS TO SIMULATION

by

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1. The Sequential Allocation Method

Bebbington (1975) showed that if there were N objects (such as file cards) from which it was desired to select (without replacement here and throughout) a random sample of size k without numbering the N objects, then one could proceed sequentially by selecting the first object with probability k/N and if at the r th stage s have been selected, then the $T+1$ st object is selected with probability $(k-s)/(N-T)$, $T=1,2,\dots,N-1$.

We now state and prove the extension to an arbitrary number of groups. Suppose there are N objects and it is desired to sequentially divide them randomly into r groups of size k_1, k_2, \dots, k_r , $\sum_{i=1}^r k_i = N$, i.e., each allocation has probability $1/\binom{N}{k_1, \dots, k_r}$. Let s_{1r}, \dots, s_{rr} be the number of objects selected for groups $1, 2, \dots, r$ at the T th stage and let $P_{i,T+1}$ denote the selection probability for group i at the $T+1$ st stage. Then if

$$P_{i,T+1} = (k_i - s_{iT}) / (N - T), \quad T=0,1,\dots,N-1, \quad (1.1)$$

the selection is random. Note that $P_{i,1} = k_i/N$ and $\sum_{i=1}^r P_{i,T+1} = 1$. The randomness follows immediately by noting that the probability of a particular assignment is

$$\left(\prod_{i=1}^r k_i! \right) / N! = 1 / \binom{N}{k_1, \dots, k_r}.$$

Bebbington's (1975) result is a special case of the above when $r=2$.

As an example, suppose $r=3$, $k_1=2$, $k_2=2$, $k_3=3$ and $N=7$. In order to make the sequential allocation given by (1.1) we take

A Sequential k-Group Random Allocation Method with Applications to Simulation

Andrew P. Soms*

Abstract

A sequential method of random allocation is given and it is shown how it can be used to estimate the observed significance levels of k -sample nonparametric tests. The sequential technique is compared to the standard random allocation technique and shown to be more efficient. An application is made to the Dunn-Bonferroni method of multiple comparisons.

AMS(MOS) Subject Classification: 62L99, 65C05

Key Words: Dunn-Bonferroni method; Nonparametric tests; Observed significance levels; Simulation

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7 independent random numbers $U_i, i = 1, 2, \dots, 7$. Let

$$Q_{0,T} = 0 \text{ and } Q_{1,T} = \sum_{j=1}^T P_j, T = 1, 2, \dots, N.$$

Then the m th object, $m = 1, 2, \dots, N$, is assigned to group n , where n is the unique integer such that

$$Q_{n-1,m} < U_m \leq Q_{n,m}.$$

Suppose the 7 random numbers are .79039, .01850, .99744, .81812, .93169, .22705, and .97709. The selection process is summarized in Table 1.

Insert Table 1 here.

Note that if all the k_i 's are one, a random permutation is produced if we think of the group as denoting position.

2. Applications to Simulation

In k-sample nonparametric tests the observed significance level of the test is obtained by considering all possible partitions M of the (possibly tied) observed values or (possibly average) ranks into r groups, computing the value of the test statistic, and counting the number of times m it is equal to or greater than the observed value. The observed significance level $\hat{\alpha}$ is then m/M . When the number of partitions is large this is prohibitive and $\hat{\alpha}$ is estimated either by simulation (taking a large random sample of the allocations) or by asymptotics. The advantage of simulation is that one can control the accuracy of the estimate (by taking a large or small random sample) depending on the importance of the situation, unlike asymptotics which each time it is used forces one into the straight-jacket of committing a usually unknown error. Since it is (perhaps regrettably) a well known fact that different actions will be taken for close values

of $\hat{\alpha}$, one above and the other below some fixed level (e.g., .01, .05, or .1) of the decision-maker, the use of simulation at least prevents approximating error in $\hat{\alpha}$ to be the determining factor.

If it is decided to use simulation, then a possible procedure is to make the random assignment as described in Section 1 many times by using a computer. The commonly used method is to produce a random permutation by ordering a random sample of uniform numbers and choosing the first k_1 indexes for group 1, the next k_2 for group 2, and so on. If all the k_i 's are one, then this is more efficient than Section 1. However, as soon as the k_i 's depart even moderately from 1, the method of Section 1 becomes much more efficient. As an example, if $k_1 = k_2 = k_3 = k_4 = 10$ and it is desired to make 2000 random assignments using a UNIVAC 1110 computer, a FORTRAN program using the methods of Section 1 uses 4.71 seconds of CPU time while a FORTRAN program using the random permutation method takes 9.17 seconds.

The Appendix contains a listing of the FORTRAN subroutine RANDM that uses the theory of Section 1 to make random assignments. This may be tied in with any specific simulation problem, e.g., the case treated in Section 3.

3. Applications to the Dunn-Bonferroni Method of Multiple Comparisons

The D-B (Dunn-Bonferroni) method is described in Dunn (1964). Briefly, let $Y_{ij}, i = 1, 2, \dots, r, j = 1, 2, \dots, n_i$, be continuous (this assumption is not important and is removed later) random variables with distribution function $F_i, H_0: F_1 = F_2 = \dots = F_r, H_a: \text{for at least one pair } (i, j), F_i \neq F_j$ in the sense of producing larger or smaller values), and the test must identify which, if any, pairs

are different. Denote by z_α the upper α^{th} point of the standard normal. The D-B test declares all those pairs (i,j) , $i < j$, different for which

$$z_{ij} = |\bar{r}_i - \bar{r}_j| / \left[\frac{(N)(N+1)}{12} \left(\frac{1}{n_i} + \frac{1}{n_j} \right) \right]^{1/2} \geq z_\alpha / (k(k-1)) \quad (3.1)$$

where \bar{r}_i denotes the average of the ranks of the i^{th} group in the joint ranking. The nominal significance level of this procedure is α . The actual significance level α_A is

$$\alpha_A = P_0 \left(\max_{1 \leq j} z_{ij} \geq z_\alpha / (k(k-1)) \right) \quad (3.2)$$

and may be obtained by simulation based on Section 1. Table 2 gives some comparisons of nominal with actual, using Section 1 and 10,000 simulations.

Insert Table 2 here.

The Appendix contains a listing of the program used for Table 2. It thus appears that D-B is conservative and we can remove the conservatism by substituting for $z_\alpha / (k(k-1))$ $d_{(1)}$, $i = 1, 2, \dots, r(r-1)/2$, is the i^{th} largest observed values of z_{ij} , $i < j$, to obtain by simulation the $r(r-1)/2$ possible observed significance levels.

The K-S (Kruskal-Scheffé) method is also sometimes used in this situation (see, e.g., Miller, 1966, p. 166) and consists of replacing $z_\alpha / (r(r-1))$ in (3.1) with $h_\alpha^{1/2} = (\chi_{\alpha, r-1}^2)^{1/2}$, where $\chi_{\alpha, r-1}^2$ is the upper α^{th} point of χ^2 with $r-1$ degrees of freedom. The comparison of the critical constants in Table 3 shows that this is even more conservative than D-B.

Insert Table 3 here.

If the data is discrete, the D-B method can be modified as in Dunn (1964) and the random assignment done on average ranks. Thus ties present no problems in this approach.

The third method discussed in Miller (1964), the Steel many-one rank statistics, is too time-consuming for the simulation approach. For all practical purposes the exact D-B (use of the $d_{(1)}$ and simulation) seems the best method to use.

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EXAMPLE OF MAIN PROGRAM FOR SEQUENTIAL RANDOM ALLOCATIONS
C NO IS THE NUMBER OF GROUPS, WITH THE NUMBER OF SIMULATIONS, K'S THE GROUP
SIZES, AND THE NUMBERS TO BE ALLOCATED

```

DIMENSION X(1000),Z(20,100),K(20)
DO 100 I=1,20
  DO 200 J=1,100
    IF (N0EQ,0) GO TO 101
    IF (N0,0) GO TO 101
    GO TO 100,2(0),J+1,N0
  200 CONTINUE
  GO TO 100
100 CONTINUE
  DO 300 J=1,100
    IF (N0EQ,0) GO TO 301
    IF (N0,0) GO TO 301
    GO TO 300,2(0),J+1,N0
  300 CONTINUE
  GO TO 300
300 CONTINUE
  DO 400 J=1,100
    IF (N0EQ,0) GO TO 401
    IF (N0,0) GO TO 401
    GO TO 400,2(0),J+1,N0
  400 CONTINUE
  GO TO 400
400 CONTINUE
  DO 500 J=1,100
    IF (N0EQ,0) GO TO 501
    IF (N0,0) GO TO 501
    GO TO 500,2(0),J+1,N0
  500 CONTINUE
  GO TO 500
500 CONTINUE
  DO 600 J=1,100
    IF (N0EQ,0) GO TO 601
    IF (N0,0) GO TO 601
    GO TO 600,2(0),J+1,N0
  600 CONTINUE
  GO TO 600
600 CONTINUE
  DO 700 J=1,100
    IF (N0EQ,0) GO TO 701
    IF (N0,0) GO TO 701
    GO TO 700,2(0),J+1,N0
  700 CONTINUE
  GO TO 700
700 CONTINUE
  DO 800 J=1,100
    IF (N0EQ,0) GO TO 801
    IF (N0,0) GO TO 801
    GO TO 800,2(0),J+1,N0
  800 CONTINUE
  GO TO 800
800 CONTINUE
  DO 900 J=1,100
    IF (N0EQ,0) GO TO 901
    IF (N0,0) GO TO 901
    GO TO 900,2(0),J+1,N0
  900 CONTINUE
  GO TO 900
900 CONTINUE
  DO 1000 J=1,100
    IF (N0EQ,0) GO TO 1001
    IF (N0,0) GO TO 1001
    GO TO 1000,2(0),J+1,N0
  1000 CONTINUE
  GO TO 1000
1000 CONTINUE
  DO 1100 J=1,100
    IF (N0EQ,0) GO TO 1101
    IF (N0,0) GO TO 1101
    GO TO 1100,2(0),J+1,N0
  1100 CONTINUE
  GO TO 1100
1100 CONTINUE
  DO 1200 J=1,100
    IF (N0EQ,0) GO TO 1201
    IF (N0,0) GO TO 1201
    GO TO 1200,2(0),J+1,N0
  1200 CONTINUE
  GO TO 1200
1200 CONTINUE
  DO 1300 J=1,100
    IF (N0EQ,0) GO TO 1301
    IF (N0,0) GO TO 1301
    GO TO 1300,2(0),J+1,N0
  1300 CONTINUE
  GO TO 1300
1300 CONTINUE
  DO 1400 J=1,100
    IF (N0EQ,0) GO TO 1401
    IF (N0,0) GO TO 1401
    GO TO 1400,2(0),J+1,N0
  1400 CONTINUE
  GO TO 1400
1400 CONTINUE
  DO 1500 J=1,100
    IF (N0EQ,0) GO TO 1501
    IF (N0,0) GO TO 1501
    GO TO 1500,2(0),J+1,N0
  1500 CONTINUE
  GO TO 1500
1500 CONTINUE
  DO 1600 J=1,100
    IF (N0EQ,0) GO TO 1601
    IF (N0,0) GO TO 1601
    GO TO 1600,2(0),J+1,N0
  1600 CONTINUE
  GO TO 1600
1600 CONTINUE
  DO 1700 J=1,100
    IF (N0EQ,0) GO TO 1701
    IF (N0,0) GO TO 1701
    GO TO 1700,2(0),J+1,N0
  1700 CONTINUE
  GO TO 1700
1700 CONTINUE
  DO 1800 J=1,100
    IF (N0EQ,0) GO TO 1801
    IF (N0,0) GO TO 1801
    GO TO 1800,2(0),J+1,N0
  1800 CONTINUE
  GO TO 1800
1800 CONTINUE
  DO 1900 J=1,100
    IF (N0EQ,0) GO TO 1901
    IF (N0,0) GO TO 1901
    GO TO 1900,2(0),J+1,N0
  1900 CONTINUE
  GO TO 1900
1900 CONTINUE
  DO 2000 J=1,100
    IF (N0EQ,0) GO TO 2001
    IF (N0,0) GO TO 2001
    GO TO 2000,2(0),J+1,N0
  2000 CONTINUE
  GO TO 2000
2000 CONTINUE
  DO 2100 J=1,100
    IF (N0EQ,0) GO TO 2101
    IF (N0,0) GO TO 2101
    GO TO 2100,2(0),J+1,N0
  2100 CONTINUE
  GO TO 2100
2100 CONTINUE
  DO 2200 J=1,100
    IF (N0EQ,0) GO TO 2201
    IF (N0,0) GO TO 2201
    GO TO 2200,2(0),J+1,N0
  2200 CONTINUE
  GO TO 2200
2200 CONTINUE
  DO 2300 J=1,100
    IF (N0EQ,0) GO TO 2301
    IF (N0,0) GO TO 2301
    GO TO 2300,2(0),J+1,N0
  2300 CONTINUE
  GO TO 2300
2300 CONTINUE
  DO 2400 J=1,100
    IF (N0EQ,0) GO TO 2401
    IF (N0,0) GO TO 2401
    GO TO 2400,2(0),J+1,N0
  2400 CONTINUE
  GO TO 2400
2400 CONTINUE
  DO 2500 J=1,100
    IF (N0EQ,0) GO TO 2501
    IF (N0,0) GO TO 2501
    GO TO 2500,2(0),J+1,N0
  2500 CONTINUE
  GO TO 2500
2500 CONTINUE
  DO 2600 J=1,100
    IF (N0EQ,0) GO TO 2601
    IF (N0,0) GO TO 2601
    GO TO 2600,2(0),J+1,N0
  2600 CONTINUE
  GO TO 2600
2600 CONTINUE
  DO 2700 J=1,100
    IF (N0EQ,0) GO TO 2701
    IF (N0,0) GO TO 2701
    GO TO 2700,2(0),J+1,N0
  2700 CONTINUE
  GO TO 2700
2700 CONTINUE
  DO 2800 J=1,100
    IF (N0EQ,0) GO TO 2801
    IF (N0,0) GO TO 2801
    GO TO 2800,2(0),J+1,N0
  2800 CONTINUE
  GO TO 2800
2800 CONTINUE
  DO 2900 J=1,100
    IF (N0EQ,0) GO TO 2901
    IF (N0,0) GO TO 2901
    GO TO 2900,2(0),J+1,N0
  2900 CONTINUE
  GO TO 2900
2900 CONTINUE
  DO 3000 J=1,100
    IF (N0EQ,0) GO TO 3001
    IF (N0,0) GO TO 3001
    GO TO 3000,2(0),J+1,N0
  3000 CONTINUE
  GO TO 3000
3000 CONTINUE
  DO 3100 J=1,100
    IF (N0EQ,0) GO TO 3101
    IF (N0,0) GO TO 3101
    GO TO 3100,2(0),J+1,N0
  3100 CONTINUE
  GO TO 3100
3100 CONTINUE
  DO 3200 J=1,100
    IF (N0EQ,0) GO TO 3201
    IF (N0,0) GO TO 3201
    GO TO 3200,2(0),J+1,N0
  3200 CONTINUE
  GO TO 3200
3200 CONTINUE
  DO 3300 J=1,100
    IF (N0EQ,0) GO TO 3301
    IF (N0,0) GO TO 3301
    GO TO 3300,2(0),J+1,N0
  3300 CONTINUE
  GO TO 3300
3300 CONTINUE
  DO 3400 J=1,100
    IF (N0EQ,0) GO TO 3401
    IF (N0,0) GO TO 3401
    GO TO 3400,2(0),J+1,N0
  3400 CONTINUE
  GO TO 3400
3400 CONTINUE
  DO 3500 J=1,100
    IF (N0EQ,0) GO TO 3501
    IF (N0,0) GO TO 3501
    GO TO 3500,2(0),J+1,N0
  3500 CONTINUE
  GO TO 3500
3500 CONTINUE
  DO 3600 J=1,100
    IF (N0EQ,0) GO TO 3601
    IF (N0,0) GO TO 3601
    GO TO 3600,2(0),J+1,N0
  3600 CONTINUE
  GO TO 3600
3600 CONTINUE
  DO 3700 J=1,100
    IF (N0EQ,0) GO TO 3701
    IF (N0,0) GO TO 3701
    GO TO 3700,2(0),J+1,N0
  3700 CONTINUE
  GO TO 3700
3700 CONTINUE
  DO 3800 J=1,100
    IF (N0EQ,0) GO TO 3801
    IF (N0,0) GO TO 3801
    GO TO 3800,2(0),J+1,N0
  3800 CONTINUE
  GO TO 3800
3800 CONTINUE
  DO 3900 J=1,100
    IF (N0EQ,0) GO TO 3901
    IF (N0,0) GO TO 3901
    GO TO 3900,2(0),J+1,N0
  3900 CONTINUE
  GO TO 3900
3900 CONTINUE
  DO 4000 J=1,100
    IF (N0EQ,0) GO TO 4001
    IF (N0,0) GO TO 4001
    GO TO 4000,2(0),J+1,N0
  4000 CONTINUE
  GO TO 4000
4000 CONTINUE
  DO 4100 J=1,100
    IF (N0EQ,0) GO TO 4101
    IF (N0,0) GO TO 4101
    GO TO 4100,2(0),J+1,N0
  4100 CONTINUE
  GO TO 4100
4100 CONTINUE
  DO 4200 J=1,100
    IF (N0EQ,0) GO TO 4201
    IF (N0,0) GO TO 4201
    GO TO 4200,2(0),J+1,N0
  4200 CONTINUE
  GO TO 4200
4200 CONTINUE
  DO 4300 J=1,100
    IF (N0EQ,0) GO TO 4301
    IF (N0,0) GO TO 4301
    GO TO 4300,2(0),J+1,N0
  4300 CONTINUE
  GO TO 4300
4300 CONTINUE
  DO 4400 J=1,100
    IF (N0EQ,0) GO TO 4401
    IF (N0,0) GO TO 4401
    GO TO 4400,2(0),J+1,N0
  4400 CONTINUE
  GO TO 4400
4400 CONTINUE
  DO 4500 J=1,100
    IF (N0EQ,0) GO TO 4501
    IF (N0,0) GO TO 4501
    GO TO 4500,2(0),J+1,N0
  4500 CONTINUE
  GO TO 4500
4500 CONTINUE
  DO 4600 J=1,100
    IF (N0EQ,0) GO TO 4601
    IF (N0,0) GO TO 4601
    GO TO 4600,2(0),J+1,N
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C D-R BY STIMULATION
C NR- IS THE NUMBER OF GROUPS, NSIN THE NUMBER OF STIMULATIONS, ZAL IS THE POINT
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C STANDARDIZED RANK AVERAGE DIFFERENCES EQUALLYING OR EXCEEDING IT IS TO BE
C CALCULATED, N'S ARE THE GROUP SIZES

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1. Selection Process

Stage	Random Digit	P _{1T}	P _{2T}	P _{3T}	Group Selected
1	.79039	2/7	2/7	3/7	3
2	.01850	2/6	2/6	2/6	1
3	.99744	1/5	2/5	2/5	3
4	.01812	1/4	2/4	1/4	3
5	.93169	1/3	2/3	0	2
6	.22705	1/2	1/2	0	1
7	.97709	0	1	0	2

2. Comparison of Actual to Nominal α

r	Common Group Size	Actual α	
		Nominal α	Actual α
3	5	.05	.037
3	10	.05	.040
3	15	.05	.043
3	30	.05	.045
3	5	.01	.0030
3	10	.01	.0077
3	15	.01	.0077
3	30	.01	.010
5	5	.05	.026
5	10	.05	.036
5	5	.01	.0030
5	10	.01	.0067

3. Comparison of D-B and K-S Critical Constants

r	$\frac{z_{.05}/(r(r-1))}{(\chi^2_{.05;r-1})^{1/2}}$	$\frac{z_{.01}/(r(r-1))}{(\chi^2_{.01;r-1})^{1/2}}$	$\frac{z_{.01}/(r(r-1))}{(\chi^2_{.01;r-1})^{1/2}}$
3	2.39	2.79	2.94
4	2.50	3.08	3.02
5	2.58	3.33	3.09
6	2.64	3.55	3.15
7	2.69	3.75	3.19
8	2.74	3.94	3.23
9	2.77	4.11	3.26
10	2.81	4.28	3.29

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